United States Environmental Protection Agency

Industrial Waste Management Evaluation Model (IWEM) Technical Background Document

Office of Solid Waste and Emergency Response (5305W)
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ACRONYMS AND ABBREVIATIONS

1-D	One-dimensional
3-D	Three-dimensional
API	American Petroleum Institute
CDF	Cumulative (Probability) Density Function
cm/sec	centimeters per second
CQA	Construction Quality Assurance
CSF	Cancer Slope Factor
CSFi	Inhalation Cancer Slope Factor
CSFo	Oral Cancer Slope Factor
DAF	Dilution and Attenuation Factor
DOM	Dissolved Organic Matter
EPA	Environmental Protection Agency
EPACMTP	EPA-Composite Model for Leachate Migration with Transformation Products
FeOOH	Goethite
FeOx	Ferric oxide
GUI	Graphical User Interface
HBN	Health-Based Number
HDPE	High-Density Polyethylene
HELP	Hydrologic Evaluation of Landfill Performance
HGDB	Hydrogeologic Database for Ground-Water Modeling
HQ	Hazard Quotient
HWIR	Hazardous Waste Identification Rule
in/yr	inches per year
IWEM	Industrial Waste Management Evaluation Model
k_d	Soil-Water Partition Coefficient
kg/m^3	kilograms per cubic meter
K_{oc}	Organic Carbon Partition Coefficient
L/kg	Liters per kilogram
LAI	Leaf Area Index
LAU	Land Application Unit
LCTV	Leachate Concentration Threshold Value
LDS	Leak Detection System

ACRONYMS AND ABBREVIATIONS (continued)

LF	Landfill
LOA	Leachate organic acids
m^2/yr	meters squared per year
MCL	Maximum Contaminant Level
mg/kg/day	milligram per kilogram per day
mg/L	Milligrams per liter
MINTEQA2	EPA's geochemical equilibrium speciation model for dilute aqueous systems
mm^2	Millimeters squared
Mton	Mega-ton
POM	Particulate Organic Matter
RfC	Reference Concentration
RfD	Reference Dose
RGC	Reference Ground-Water Concentration
SCL	Silty Clay Loam
SCS	Soil Conservation Service
SDWA	Safe Drinking Water Act
SI	Surface Impoundment
SLT	Silt Loam
SNL	Sandy Loam
SPLP	Synthetic Precipitation Leaching Procedure
TC	Toxicity Characteristic
TC Rule	Toxicity Characteristic Rule
TCLP	Toxicity Characteristic Leaching Procedure
TOC	Total Organic Carbon
URF	Unit Risk Factor
WMU	Waste Management Unit
WP	Waste Pile

EXECUTIVE SUMMARY

Objectives

This document provides technical background on the assumptions, methodologies and data used by the U.S. Environmental Protection Agency (EPA) to develop Tier 1 and Tier 2 ground-water impact evaluation tools as part of the Agency's *Guide for Industrial Waste Management* (hereafter, the *Guid*e). The evaluation tools are combined in the Industrial Waste Management Evaluation Model (IWEM).

The EPA and representatives from 12 state environmental agencies have developed a voluntary *Guide* to recommend a baseline of protective design and operating practices to manage nonhazardous industrial waste throughout the country. The guidance was designed for facility managers, regulatory agency staff, and the public, and it reflects four underlying objectives:

- Adopt a multimedia approach to protect human health and the environment;
- Tailor management practices to risk using the innovative, user-friendly modeling tools provided in the *Guide;*
- Affirm state and tribal leadership in ensuring protective industrial waste management, and use the *Guide* to complement state and tribal programs; and
- Foster partnerships among facility managers, the public, and regulatory agencies.

The *Guide* recommends best management practices and key factors to consider to protect ground water, surface water, and ambient air quality in siting, operating, and designing waste management units (WMUs); monitoring WMUs' impact on the environment; determining necessary corrective action; closing WMUs; and providing post-closure care. In particular, the Guide recommends risk-based approaches to design liner systems, determine waste application rates for ground-water protection, and evaluate the need for air controls. The CD-ROM version of the *Guide* includes user-friendly air and ground-water models to conduct these risk evaluations. The IWEM software described in this *Background Document* is the ground-water tool that was developed to support the *Guide*.

The IWEM software helps determine the most appropriate WMU design to minimize or avoid adverse ground-water impacts, by evaluating one or more types of liners, the hydrogeologic conditions of the site, and the toxicity and expected leachate concentrations of the anticipated waste constituents.

For the ground-water pathway, the *Guide* recommends a tiered approach that is based on modeling the fate and transport of waste constituents through subsurface soils to a ground-water well[1] to produce a liner recommendation (or a recommendation concerning land application) that protects human health and the environment. The successive tiers in the analysis incorporate more site-specific data to tailor protective management practices to the particular circumstances at the modeled site:

- **Tier 1**: A screening analysis based upon national distributions of data;
- **Tier 2**: A location-adjusted analysis using a limited set of the most sensitive waste- and site-specific data; and
- **Tier 3**: A comprehensive and detailed site assessment

The IWEM software is designed to support the Tier 1 and Tier 2 analyses. The IWEM tool compares the expected leachate concentration for each waste constituent entered by the user with leachate concentration threshold values (LCTVs) calculated by a ground-water fate and transport model for three standard liner types. The IWEM software compiles the results for all constituents expected in the leachate and then reports the minimum liner scenario that is protective for all constituents. Table EX-1 shows the WMU types and liner types that are evaluated in IWEM.

Table EX-1 IWEM WMU and Liner Combinations

WMU Type	Liner Type		
	No Liner (in-situ soil)	Single Clay Liner	Composite Liner
Landfill	✔	✔	✔
Surface Impoundment	✔	✔	✔
Waste Pile	✔	✔	✔
Land Application Unit	✔	N/A	N/A

N/A = Not Applicable

For land application units (LAUs) only the *No Liner* scenario is evaluated because liners are not typically used for this type of unit.

[1] In IWEM, the term "well" is used to represent an actual or hypothetical ground-water monitoring well or drinking-water well, located downgradient from a WMU.

Waste Management Units

Four WMUs are represented in the IWEM Tier 1 and Tier 2 tool and have the following key characteristics:

- ***Landfill (LF).*** IWEM considers closed LFs with an earthen cover and either no-liner, a single clay liner, or a composite, clay-geomembrane liner. The release of waste constituents into the soil and ground water underneath the LF is caused by dissolution and leaching of the constituents due to precipitation which percolates through the LF. The type of liner which is present controls, to a large extent, the amount of leachate which is released from the unit. Because the LF is closed, the concentration of the waste constituents will diminish with time due to depletion of LF wastes. The leachate concentration value which is used an IWEM input is the expected initial leachate concentration, when the waste is "fresh".

- ***Waste Pile (WP).*** WPs are typically used as temporary storage units for solid wastes. Due to their temporary nature, they typically will not be covered. IWEM does allow liners to be present, similar to LFs. In Tier 1 analyses, IWEM assumes that WPs have a fixed operational life of 40 years, after which the WP is removed. IWEM therefore models WPs as a temporary source.

- ***Surface Impoundment (SI).*** In IWEM, SIs are ground level or below-ground level, flow-through units, which may be unlined, have a single clay liner, or a composite liner. Release of leachate is driven by the ponding of water in the impoundment, which creates a hydraulic head gradient with the ground water underneath the unit.

- ***Land Application Unit (LAU).*** LAUs (or land treatment units) are areas of land which received regular applications of waste that can be either tilled or sprayed directly onto the soil and subsequently mixed with the soil. IWEM models the leaching of wastes after tilling with soil. IWEM does not account for the losses due to volatilization during or after waste application. Only the no-liner scenario is evaluated for LAUs because liners typically are not used for this type of unit.

Tier 1 and Tier 2 Evaluations

Tier 1 and Tier 2 evaluations in IWEM can be summarized as follows:

Tier 1: Using only the expected leachate concentrations of constituents in a waste, generic tables provide WMU design recommendations (liner system or maximum allowable leachate concentration). If the waste contains several constituents, the Tier 1 evaluation will choose the most protective design indicated for any of the constituents. This tier of the analysis uses national data and generally will recommend more stringent controls. The Tier 1 evaluation is designed to be protective for 90% of the potential waste sites across the United States.

Tier 2 : In Tier 2, site-specific data for up to twenty of the most sensitive WMU and hydrogeologic characteristics can be entered to assess whether a particular design will be protective. In addition, some default constituent fate parameters can be modified, including adding biodegradation. This tier is generally more representative because it allows the user to incorporate some site-specific information in the analysis.

In Tier 1, the only required IWEM inputs are the type of WMU to be evaluated, the waste constituents present in the leachate, and the expected leachate concentration value of each constituent.

In Tier 2, there are a small number of required site-specific user-input parameters in addition to the Tier 1 inputs, as well as a number of optional site-specific user-input parameters. The additional required site-specific Tier 2 parameters are:

- WMU Area
- WMU Depth (LF and SI)
- WMU location (to select the appropriate climate parameters)

Optional site-specific Tier 2 inputs are:

- Distance to the nearest surface water body (SI)
- Depth of the base of the WMU below ground surface (LF, SI, and WP)
- Operational Life of the WMU (SI, WP, and LAU)
- Sludge Thickness (SI)
- Waste Type (WP)
- Leakage (infiltration) rate from the WMU
- Distance to the nearest down-gradient well
- Unsaturated zone soil type

- Hydrogeologic Environment, and/or individual values of:
  - Depth from the base of the WMU to the water table
  - Saturated thickness of the upper aquifer
  - Hydraulic conductivity in the saturated zone
  - Regional hydraulic gradient in the saturated zone
  - Ground-water pH
- Constituent fate parameters:
  - sorption coefficient (K_d)
  - (bio-)degradation rate
- Constituent-specific reference ground water concentrations, and corresponding exposure durations.

EPACMTP Ground Water Fate and Transport Model

IWEM uses the EPA's Composite Model for Leachate Migration with Transformation Products (EPACMTP) to model the fate and transport of constituents in the subsurface as they migrate through the subsurface. Figure EX.1 shows a conceptual, cross-sectional view of the aquifer system modeled by EPACMTP.

EPACMTP simulates fate and transport in both the unsaturated zone and the saturated zone (ground water) using the advection-dispersion equation with terms to account for equilibrium sorption and first-order transformation. The source of constituents is a WMU located at the ground surface overlying an unconfined aquifer. The base of the WMU can be below the actual ground surface. Waste constituents leach from the base of the WMU into the underlying soil. They migrate vertically downward until they reach the water table. As the leachate enters the ground water, it will mix with ambient ground water (which is assumed to be free of pollutants) and a ground-water plume will develop which extends in the direction of downgradient ground-water flow. EPACMTP accounts for the spreading of the plume in all three dimensions.

Leachate generation is driven by the infiltration of precipitation that has percolated through the waste unit, from the base of the WMU into the soil. Different liner designs control the rate of infiltration that can occur. EPACMTP models flow in the unsaturated zone, and in the saturated zone as steady-state processes, that is, representing long-term average conditions.

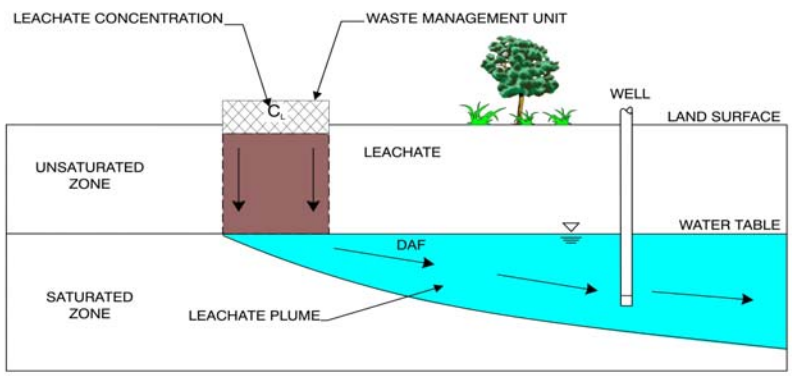

Figure EX.1 Conceptual Cross-Section View of the Subsurface System Simulated by EPACMTP.

In addition to dilution of the constituent concentration caused by the mixing of the leachate with ground water, EPACMTP accounts for attenuation due to sorption of waste constituents in the leachate onto soil and aquifer solids, and for bio-chemical transformation (degradation) processes in the unsaturated and saturated zone. In Tier 1, and by default in Tier 2, EPACMTP only accounts for chemical transformations caused by hydrolysis reactions. In Tier 2 analyses, however, you can use site-specific biodegradation rates. EPACMTP simulates all transformation processes as first-order reactions, that is, as processes that can be characterized with a half-life.

For organic constituents, EPACMTP models sorption between the constituents and the organic matter in the soil or aquifer, based on constituent-specific organic carbon partition coefficients, and a site-specific organic carbon fraction in the soil and aquifer. In the case of metals, EPACMTP accounts for more complex geochemical reactions by using effective sorption isotherms for a range of aquifer geochemical conditions, generated using EPA's geochemical equilibrium speciation model for dilute aqueous systems (MINTEQA2).

The output from EPACMTP is the predicted maximum ground-water exposure concentration, measured at a well situated down-gradient from a WMU. In Tier 1 the well is always located on the plume centerline at a fixed distance of 150 meters from the downgradient edge of the WMU. In Tier 2, the well is also restricted to be on the plume centerline, but the distance (up to one mile) can be entered as a site-specific value.

Monte Carlo Implementation

In developing the Tier 1 and Tier 2 evaluation, EPA uses Monte Carlo simulation to determine the probability distribution of predicted ground-water concentrations, as a function of the variability of modeling input parameters. The Monte Carlo technique is based on the repeated random sampling of input parameters from their respective frequency distribution, executing the EPACMTP fate and transport model for each realization of input parameter values. At the conclusion of the Monte Carlo analysis, it is then possible to construct a probability distribution of ground-water concentration values and associated ground-water dilution and attenuation factors (DAFs). Tier 1 and Tier 2 results are based on Monte Carlo analyses of 10,000 realizations.

For Tier 1, we used a series of databases that describe the expected nationwide variations in climate, soil, and hydrogeological conditions. In order to determine Tier 1 WMU design recommendations, we used the 90th percentile of the predicted nationwide distribution of ground-water concentration values. Tier 1 results are therefore designed to be protective of 90% of waste sites in the United States. The advantage of a Tier 1 evaluation is that it is very rapid and does not require site-specific information. The trade-off is that while the Tier 1 evaluation will provide a protective screening assessment for the majority of waste sites, it is not possible to guarantee that it will be protective at all sites.

A Tier 2 evaluation uses information on waste site location and other site-specific data, to perform a more precise (less uncertain) assessment. If appropriate for site conditions (e.g., an arid climate), it may be possible to avoid unnecessarily costly WMU designs. It may also provide an additional level of certainty that liner designs are protective of sites in vulnerable settings, such as high rainfall and shallow ground water. If site-specific data for ground-water modeling parameters are not available, values are drawn randomly (except for the required parameters that the user must input). The underlying assumption at Tier 2 is that if a site-specific parameter value is not available, the uncertainty in the value of the parameter is captured by the nationwide range in values of that parameter. The resulting location-specific Tier 2 predicted ground-water concentrations therefore represent a 90th percentile protection level for the specified site conditions.

Reference Ground-Water Concentrations

Reference Ground-Water Concentrations (RGCs) are maximum allowable concentrations of constituents in ground water. The IWEM Tier 1 and Tier 2 evaluations incorporate two types of RGCs:

1) ***Maximum Contaminant Levels (MCLs)***. MCLs are available for some IWEM constituents. MCLs are maximum permissible constituent concentrations allowed in public drinking water and are established under the Safe Drinking Water Act (SDWA). In developing MCLs, EPA considers not only a constituent's health effects, but also additional factors, such as the cost of treatment.

2) ***Health-based numbers (HBNs)***. EPA developed HBNs for residential exposures via ingestion and inhalation routes of exposure. HBNs are the maximum constituent concentrations in ground water that we expect will not usually cause adverse noncancer health effects in the general population (including sensitive subgroups), or that will not result in an additional incidence of cancer in more than approximately one in one million individuals exposed to the constituent.

HBNs were developed for carcinogenic and non-carcinogenic effects. In the case of inhalation, this exposure route was evaluated for volatile organic constituents and mercury. HBN values were calculated by "rearranging" standard EPA risk equations to calculate constituent concentration, rather than cancer risk or noncancer hazard. The IWEM HBNs correspond to a "target risk" and a "target hazard quotient (HQ)." The target risk for carcinogens is 1×10^{-6} (one in one million). The target HQ for noncarcinogens is 1 (unitless). A HQ of 1 indicates that the estimated dose is equal to the Reference Dose (RfD) and, therefore, a HQ of 1 is frequently EPA's threshold of concern for noncancer effects. These targets were used to calculate separate HBNs for each constituent of concern, and separate HBNs for each exposure route of concern (ingestion or inhalation). The Tier 1 and Tier 2 evaluations do not consider combined exposure from ground-water ingestion (from drinking water) and ground-water inhalation (from showering), nor do they consider the potential for additive exposure to multiple constituents.

Leachate Concentration Threshold Values and Liner Recommendations

The IWEM tool provides recommendations for waste management in terms of LCTVs and type of liner. LCTVs represent the highest concentration in leachate that is protective of human health for a particular WMU and liner scenario. In Tier 1, the liner recommendations are based on comparing expected waste leachate concentrations to tabulated LCTVs. In Tier 2, IWEM uses ground-water modeling to predict expected waste- and site-specific ground-water exposure concentrations for all waste constituents. IWEM then compares the exposure concentrations to RGCs to determine whether or not a liner design is protective. In the Tier 2 analysis, IWEM calculates LCTVs to help users determine whether waste minimization may be appropriate to meet a specific liner design. Because the Tier 2 analysis includes site-specific considerations, LCTVs from this analysis are not applicable to other sites. The basic calculation of LCTVs can be summarized as follows:

$$LCTV = DAF \times RGC$$

where:

LCTV	=	Leachate Concentration Threshold Value
DAF	=	Dilution and Attenuation Factor
RGC	=	Reference Ground-Water Concentration

In this relationship, DAF represents the reduction in constituent concentration between the WMU leachate, and the eventual ground-water exposure concentration at a downgradient ground-water receptor well. The DAF is chemical- and site-specific and is calculated using EPACMTP. DAF values used in IWEM represent 90th percentile levels. In other words, the LCTVs are designed to be protective with a 90% certainty.

The RGC accounts for a constituent's regulatory (MCL) or risk-based (HBN) standard. As expressed in the relationship above, the LCTV is directly proportional to the RGC. Thus, LCTVs for constituents with similar DAFs will differ based on the difference in the regulatory or risk-based standards.

For some constituents, the LCTVs are based not only on toxicity and DAFs, but also on other criteria that are applied to cap the model-calculated values. IWEM caps leachate concentrations from an industrial solid WMU at a level no higher than 1000 mg/l for any single constituent. Concentrations higher than this level may indicate the pressure of free-product conditions which are outside the validity of IWEM.

The 39 hazardous waste toxicity characteristic (TC) constituents are capped at their TC levels because concentrations above those levels are hazardous waste. For the 18 constituents that hydrolyze, LCTVs may be capped by toxic daughter products. The final LCTVs are then calculated such that they accommodate both the parent constituent as well as any toxic daughter products. For instance, if a parent waste constituent rapidly hydrolyzes into a persistent daughter product, the ground-water exposure caused by the parent itself may be minimal (it has already degraded before it reaches the well), but the final LCTV and liner recommendation generated by IWEM would be based on the exposure caused by the daughter product, under the assumption that the parent compound fully transforms into the daughter product. If a IWEM constituent has more than one toxic daughter product, the final LCTV and liner recommendation take all daughter products into account.

The final IWEM liner recommendations are based on the minimum liner design that is protective for all constituents. In applying the IWEM tool, a Tier 1 screening evaluation is typically performed first. If the expected leachate concentrations of all waste constituents are lower than their respective no-liner LCTVs, the proposed WMU does not need a liner to protect ground water. If any constituent concentration is higher than the corresponding no-liner LCTV, than a single or composite liner would be recommended. If any constituent is higher than the corresponding single liner LCTV, than the recommendation is at least a composite liner. Because a Tier 1 evaluation is designed to be protective of sites across the United States, if the analysis indicates that no liner is recommended, it is generally not necessary to proceed to a Tier 2 evaluation. On the other hand, if the Tier 1 analysis indicates a liner is recommended, a user may wish to confirm this recommendation by proceeding to a Tier 2 (or Tier 3) analysis for at least those constituents whose expected leachate concentrations indicate that a liner is recommended.